1.1 Petroleum Systems (CRF Source Category 1B2a)

Methane emissions from petroleum systems are primarily associated with onshore and offshore crude oil production, transportation, and refining operations. During these activities, CH_4 is released to the atmosphere as leak emissions, vented emissions (including emissions from operational upsets) and emissions from fuel combustion. Leak and vented CO_2 emissions from petroleum systems are primarily associated with crude oil production and refining operations but are negligible in transportation operations. Total CH_4 emissions from petroleum systems in 2017 were 37.7 MMT CO_2 Eq. (1,506 kt), a decrease of 10 percent from 1990. Total CO_2 emissions from petroleum systems in 2017 were 23.3 MMT CO_2 Eq. (23,336 kt), an increase of 161 percent from 1990. Total N_2O emissions from petroleum systems in 2017 were 0.02 MMT CO_2 Eq. (0.08 kt), an increase of 77 percent from 1990.

Each year, some estimates in the Inventory are recalculated with improved methods and/or data. These improvements are implemented consistently across the previous Inventory's time series (i.e., 1990 to 2016) to ensure that the trend is accurate. Recalculations in petroleum systems in this year's Inventory include:

- Revised hydraulically fractured (HF) oil well completions and workovers methodology to use GHGRP data
- Newly calculated N_2O emissions from flaring
- Newly calculated CO_2 emissions from crude oil transportation
- Recalculations due to GHGRP submission revisions

The Recalculations Discussion section below provides more details on the updated methods.

Exploration. Exploration includes well drilling, testing, and completions. Exploration accounts for approximately 1 percent of total CH_4 emissions from petroleum systems. The predominant sources of emissions from exploration are hydraulically fractured oil well completions and well testing. Other sources include well completions without hydraulic fracturing and well drilling. Since 1990, exploration CH_4 emissions have decreased 88 percent, and while the number of hydraulically fractured wells completed increased by a factor of nearly 3, there were decreases in the fraction of such completions without reduced emissions completions (RECs) or flaring (from 90 percent in 1990 to 2 percent in 2017). Emissions of CH_4 from exploration were highest in 2012, over 20 times higher than in 2017, and lowest in 2017. Emissions of CH_4 from exploration decreased 24 percent from 2016 to 2017. Exploration accounts for 7 percent of total CO_2 emissions from petroleum systems in 2017. Emissions of CO_2 from exploration in 2017 increased by a factor of 4.2 from 1990, and 38 percent from 2016, due to an increase in hydraulically fractured oil well completions with flaring (from 10 percent of completions in 1990 to 58 percent in 2017). Emissions of CO_2 from exploration were highest in 2014, around 1.8 times as high as in 2017. Exploration accounts for 3 percent of total N_2O emissions from petroleum systems in 2017. Emissions of N_2O from exploration in 2017 increased by a factor of 3.4 from 1990, and 22 percent from 2016, due to an increase in hydraulically fractured oil well completions with flaring (from 10 percent of completions in 1990 to 58 percent in 2017).

Production. Production accounts for approximately 97 percent of total CH_4 emissions from petroleum systems. The predominant sources of emissions from production field operations are pneumatic controllers, offshore oil platforms, gas engines, chemical injection pumps, leaks from oil wellheads, and oil tanks. These six sources together account for 91 percent of the CH_4 emissions from production. Since 1990, CH_4 emissions from production have decreased by 5 percent, due to decreases in emissions from tanks, hydraulically fractured oil well workovers, and offshore platforms. Overall, production segment methane emissions decreased by 1 percent from 2016 levels. Production emissions account for 77 percent of the total CO_2 emissions from petroleum systems in 2017. The principal sources of CO_2 emissions are associated gas flaring, oil tanks with flares, and miscellaneous production flaring. These three sources together account for 98 percent of the CO_2 emissions from production. Since 1990, CO_2 emissions from production have increased by 236 percent, due to increases in flaring emissions from associated gas flaring, tanks, and miscellaneous production flaring. Overall, production segment CO_2 emissions increased by 6 percent from 2016 levels due to an increase in associated gas flaring and miscellaneous production flaring. Production emissions account for 52 percent of the total N_2O emissions from petroleum systems. The principal sources of N_2O emissions

are associated gas flaring, oil tanks with flares, and miscellaneous production flaring. Since 1990, N_2O emissions from production have increased by 186 percent.

Crude Oil Transportation. Crude oil transportation activities account for less than 1 percent of total CH_4 emissions from petroleum systems. Emissions from tanks, marine loading, and truck loading operations account for 73 percent of CH_4 emissions from crude oil transportation. Since 1990, CH_4 emissions from transportation have increased by 17 percent. Methane emissions from transportation in 2017 decreased 5 percent from 2016 levels. Crude oil transportation activities account for less than 0.01 percent of total CO_2 emissions from petroleum systems. Emissions from tanks, marine loading, and truck loading operations account for 73 percent of CO_2 emissions from crude oil transportation. Emissions from crude oil transportation account for a very small percentage of the total emissions from petroleum systems and have little impact on the overall emissions.

Crude Oil Refining. Crude oil refining processes and systems account for 2 percent of total CH_4 emissions from petroleum systems. This low share is because most of the CH_4 in crude oil is removed or escapes before the crude oil is delivered to the refineries. There is an insignificant amount of CH_4 in all refined products. Within refineries, flaring accounts for 41 percent of the CH_4 emissions, while uncontrolled blowdowns and process vents account for 19 and 16 percent, respectively. Methane emissions from refining of crude oil have increased by 16 percent since 1990, and increased less than 1 percent since 2016; however, similar to the transportation subcategory, this increase has had little effect on the overall emissions of CH_4. Crude oil refining processes and systems account for 16 percent of total CO_2 emissions from petroleum systems. Almost all (about 97 percent) of the CO_2 from refining is from flaring. Refinery CO_2 emissions increased by 14 percent from 1990 to 2017, and decreased by 7 percent from 2016 levels. Flaring occuring at crude oil refining processes and systems accounts for 45 percent of total N_2O emissions from the oil industry. Refinery N_2O emissions increased by 19 percent from 1990 to 2017, and decreased by 6 percent from 2016 levels.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: CH_4 Emissions from Petroleum Systems (MMT CO_2 Eq.)

Activity	1990	2005	2013	2014	2015	2016	2017
Exploration[a]	**3.0**	**4.5**	**6.3**	**5.0**	**2.1**	**0.5**	**0.4**
Production (Total)	**38.3**	**31.4**	**34.4**	**36.2**	**36.5**	**36.8**	**36.4**
Pneumatic Controllers	19.3	17.5	18.6	19.4	19.6	20.5	20.9
Offshore Platforms	5.3	4.6	4.7	4.7	4.7	4.7	4.7
Equipment Leaks[b]	2.2	2.2	2.6	2.7	2.7	2.6	2.5
Gas Engines	2.1	1.7	2.2	2.3	2.3	2.2	2.2
Chemical Injection Pumps	1.2	1.7	2.1	2.2	2.2	2.1	2.0
Tanks	5.4	1.5	1.3	1.6	1.7	2.6	1.5
Other Sources	2.6	2.1	2.9	3.3	3.3	2.2	2.5
Crude Oil Transportation	**0.2**	**0.1**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Refining	**0.6**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**
Total	**42.1**	**36.7**	**41.6**	**42.1**	**39.5**	**38.2**	**37.7**

[a] Exploration includes well drilling, testing, and completions.

[b] Includes leak emissions from wellheads, separators, heaters/treaters, and headers.

Note: Totals may not sum due to independent rounding.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: CH_4 Emissions from Petroleum Systems (kt CH_4)

Activity	1990	2005	2013	2014	2015	2016	2017
Exploration[a]	**121**	**181**	**254**	**201**	**84**	**19**	**14**
Production (Total)	**1,531**	**1,255**	**1,377**	**1,446**	**1,458**	**1,473**	**1,456**
Pneumatic Controllers	774	701	743	777	786	818	837
Offshore Platforms	211	185	188	188	188	188	188
Equipment Leaks	88	86	104	109	107	104	102
Gas Engines	86	70	88	93	93	89	89
Chemical Injection Pumps	49	68	84	87	86	83	82
Tanks	218	60	53	63	68	102	61
Other Sources	105	86	118	131	131	89	98
Crude Oil Transportation	**7**	**5**	**7**	**8**	**8**	**8**	**8**
Refining	**24**	**28**	**27**	**26**	**28**	**28**	**28**
Total	**1,682**	**1,469**	**1,665**	**1,682**	**1,579**	**1,528**	**1,506**

[a] Exploration includes well drilling, testing, and completions.
Note: Totals may not sum due to independent rounding.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: CO_2 Emissions from Petroleum Systems (MMT CO_2)

Activity	1990	2005	2013	2014	2015	2016	2017
Exploration	0.3	0.3	2.5	3.0	2.2	1.2	1.7
Production	5.3	7.5	19.1	23.2	25.4	17.0	18.0
Transportation	+	+	+	+	+	+	+
Crude Refining	3.3	3.7	3.6	3.4	4.1	4.0	3.7
Total	**9.0**	**11.6**	**25.1**	**29.6**	**31.7**	**22.2**	**23.3**

Note: Totals may not sum due to independent rounding.
+ Does not exceed 0.05 MMT CO_2.
NE (Not Estimated)

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: CO_2 Emissions from Petroleum Systems (kt CO_2)

Activity	1990	2005	2013	2014	2015	2016	2017
Exploration	321	331	2,461	2,976	2,167	1,200	1,657
Production	5,344	7,493	19,059	23,201	25,438	17,008	17,951
Transportation	0.9	0.7	1.0	1.2	1.2	1.1	1.1
Crude Refining	3,284	3,728	3,609	3,419	4,067	3,991	3,728
Total	**8,950**	**11,552**	**25,130**	**29,597**	**31,672**	**22,200**	**23,336**

Note: Totals may not sum due to independent rounding.
NE (Not Estimated)

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: N_2O Emissions from Petroleum Systems (metric tons CO_2 Eq.)

Activity	1990	2005	2013	2014	2015	2016	2017
Exploration	172	176	1,278	1,543	1,125	618	754
Production	4,414	5,332	12,980	15,817	17,429	12,749	12,640
Transportation	NE	NE	NE	NE	NE	NE	NE
Crude Refining	9,143	10,377	10,187	9,659	11,656	11,575	10,836
Total	**13,728**	**15,885**	**24,445**	**27,020**	**30,210**	**24,942**	**24,231**

Note: Totals may not sum due to independent rounding.
NE (Not Estimated)

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: N_2O Emissions from Petroleum

Systems (metric tons N_2O)

Activity	1990	2005	2013	2014	2015	2016	2017
Exploration	0.6	0.6	4.3	5.2	3.8	2.1	2.5
Production	14.8	17.9	43.6	53.1	58.5	42.8	42.4
Transportation	NE	NE	NE	NE	NE	NE	NE
Crude Refining	30.7	34.8	34.2	32.4	39.1	38.8	36.4
Total	**46.1**	**53.3**	**82.0**	**90.7**	**101.4**	**83.7**	**81.3**

Note: Totals may not sum due to independent rounding.
NE (Not Estimated)

Methodology

See Annex 3.5 for the full time series of emissions data, activity data, and emission factors, and additional information on methods and data sources.

Petroleum systems includes emission estimates for activities occurring in petroleum systems from the oil wellhead through crude oil refining, including activities for crude oil exploration, production field operations, crude oil transportation activities, and refining operations. Generally, emissions are estimated for each activity by multiplying emission factors (e.g., emission rate per equipment or per activity) by corresponding activity data (e.g., equipment count or frequency of activity).

EPA received stakeholder feedback on updates in the Inventory through EPA's stakeholder process on oil and gas in the Inventory. Stakeholder feedback is noted below in Uncertainty and Time-Series Consistency, Recalculations Discussion, and Planned Improvements.

Emission Factors. References for emission factors include *Methane Emissions from the Natural Gas Industry by the Gas Research Institute and EPA* (EPA/GRI 1996), *Estimates of Methane Emissions from the U.S. Oil Industry* (EPA 1999), DrillingInfo (2018), *Compilation of Air Pollutant Emission Factors, AP-42* (EPA 1997), *Global Emissions of Methane from Petroleum Sources* (API 1992), consensus of industry peer review panels, Bureau of Ocean Energy Management (BOEM) reports, and analysis of GHGRP data (EPA 2018).

The emission factors for pneumatic controllers and chemical injection pumps were developed using GHGRP data for reporting year 2014. The emission factors for tanks, well testing, associated gas venting and flaring, and miscellaneous production flaring were developed using GHGRP data for reporting years 2015 forward. Emission factors for hydraulically fractured (HF) oil well completions and workovers (in four control categories) were developed using GHGRP data for reporting years 2016 forward. For offshore oil production, two emission factors were calculated using data collected for all federal offshore platforms; one for oil platforms in shallow water, and one for oil platforms in deep water. For most sources, emission factors were held constant for the period 1990 through 2016, and trends in emissions reflect changes in activity levels. For tanks, well testing, and associated gas venting and flaring, year-specific emission factors were developed for years 2015 forward, and the 2015 emission factors were applied back to 1990. For miscellaneous production flaring, year-specific emission factors were developed for years 2015 forward, an emission factor of 0 was assumed for 1990 through 1992, and linear interpolation was applied to develop emission factors for 1993 through 2014. For HF oil well completions and workovers, year-specific and technology-specific emission factors were developed for years 2016 forward, and the year 2016 emission factors were applied back to 1990. Emission factors from EPA 1999 are used for all other production and transportation activities.

For associated gas venting and flaring and miscellaneous production flaring, emission factors were developed on a production basis (i.e., emissions per unit oil produced). Additionally, for these two sources, basin-specific activity and emission factors were developed for each basin that in any year from 2011 forward contributed at least 10 percent of total source emissions (on a CO_2 Eq. basis) in the GHGRP. For associated gas venting and flaring, basin-specific factors were developed for four basins: Williston, Permian, Gulf Coast, and Anadarko; for miscellaneous production flaring, basin-specific factors were developed for three basins: Williston, Permian, and Gulf Coast. Data from all other basins were combined, and activity and emission factors developed for the other basins as a single group for each emission source.

For the exploration and production segments, in general, CO_2 emissions for each source were estimated with GHGRP data or by multiplying CO_2 emission factors by the corresponding CH_4 data, as the CO_2 content of gas relates to the CH_4 content of gas. Sources with CO_2 emissions calculated from GHGRP data were HF completions and workovers, associated gas venting and flaring, tanks, well testing, pneumatic controllers, chemical injection pumps, and miscellaneous production flaring. For these sources, CO_2 was calculated using the same methods as used for CH_4. Emission factors for offshore oil production (shallow and deep water) were derived using data from BOEM. For other sources, the production field operations emission factors for CO_2 are generally estimated by multiplying the CH_4 emission factors by a conversion factor, which is the ratio of CO_2 content and CH_4 content in produced associated gas.

For crude oil transportation, emission factors for CH_4 were largely developed using data from EPA (1997), API (1992), and EPA (1999). Emission factors for CO_2 were estimated by multiplying the CH_4 emission factors by a conversion factor, which is the ratio of CO_2 content and CH_4 content in whole crude post-separator.

For petroleum refining activities, year-specific emissions from 2010 forward were directly obtained from EPA's GHGRP. All U.S. refineries have been required to report CH_4 and CO_2 emissions for all major activities starting with emissions that occurred in 2010. However, GHGRP does have provisions that refineries are not required to report to the GHGRP if their emissions fall below certain thresholds (see Planned Improvements for additional discussion). The reported total of CH_4 and CO_2 emissions for each activity was used for the emissions in each year from 2010 forward. To estimate CH_4 and CO_2 emissions for 1990 to 2009, the 2010 to 2013 emissions data from GHGRP along with the refinery feed data for 2010 to 2013 were used to derive CH_4 and CO_2 emission factors (i.e., sum of activity emissions/sum of refinery feed), which were then applied to the annual refinery feed in years 1990 to 2009.

A complete list of references for emission factors and activity data by emission source is provided in Annex 3.5.

Activity Data. References for activity data include DrillingInfo data (DrillingInfo 2018), Energy Information Administration (EIA) reports, *Methane Emissions from the Natural Gas Industry by the Gas Research Institute and EPA* (EPA/GRI 1996), *Estimates of Methane Emissions from the U.S. Oil Industry* (EPA 1999), consensus of industry peer review panels, BOEM reports, the Oil & Gas Journal, the Interstate Oil and Gas Compact Commission, the United States Army Corps of Engineers, and analysis of GHGRP data (EPA 2018).

For many sources, complete activity data were not available for all years of the time series. In such cases, one of three approaches was employed to estimate values, consistent with IPCC good practice. Where appropriate, the activity data were calculated from related statistics using ratios developed based on EPA/GRI 1996 and/or GHGRP data. In some cases, activity data are developed by interpolating between recent data points (such as from GHGRP) and earlier data points, such as from EPA/GRI 1996. Lastly, the previous year's data were used for domestic barges and tankers as current year were not yet available. For offshore production, the number of platforms in shallow water and the number of platforms in deep water are used as activity data and are taken from BOEM datasets; these activity data have not been recently updated and 2010 activity are applied for all recent years.

A complete list of references for emission factors and activity data by emission source is provided in Annex 3.5.

Uncertainty and Time-Series Consistency

In recent years, EPA has made significant revisions to the Inventory methodology to use updated activity and emissions data. To update its characterization of uncertainty, EPA has conducted a quantitative uncertainty analysis using the IPCC Approach 2 methodology (Monte Carlo Simulation technique). For more information, please see the memorandum *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016: Natural Gas and Petroleum Systems Uncertainty Estimates (2018 Uncertainty Memo)*.[1]

EPA used Microsoft Excel's @RISK add-in tool to estimate the 95 percent confidence bound around methane emissions from petroleum systems for the current Inventory, then applied the calculated bounds to both CH_4 and CO_2 emissions estimates. For the analysis, EPA focused on the four highest methane-emitting sources for the year 2017, which together emitted 79 percent of methane from petroleum systems in 2017, and extrapolated the estimated uncertainty for the remaining sources. The @RISK add-in provides for the specification of probability density functions (PDFs) for key variables within a computational structure that mirrors the calculation of the inventory

[1] See <https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems>

estimate. The IPCC guidance notes that in using this method, "some uncertainties that are not addressed by statistical means may exist, including those arising from omissions or double counting, or other conceptual errors, or from incomplete understanding of the processes that may lead to inaccuracies in estimates developed from models." As a result, the understanding of the uncertainty of emission estimates for this category evolves and improves as the underlying methodologies and datasets improve. The uncertainty bounds reported below only reflect those uncertainties that EPA has been able to quantify and do not incorporate considerations such as modeling uncertainty, data representativeness, measurement errors, misreporting or misclassification.

The results presented below provide the 95 percent confidence bound within which actual emissions from this source category are likely to fall for the year 2017, using the recommended IPCC methodology. The results of the Approach 2 uncertainty analysis are summarized in [REF _Ref284879742 \h * MERGEFORMAT]. Petroleum systems CH_4 emissions in 2017 were estimated to be between 25.0 and 51.9 MMT CO_2 Eq., while CO_2 emissions were estimated to be between 15.5 and 32.2 MMT CO_2 Eq. at a 95 percent confidence level. Uncertainty bounds for other years of the time series have not been calculated, but uncertainty is expected to vary over the time series. For example, years where many emission sources are calculated with interpolated data would likely have higher uncertainty than years with predominantly year-specific data.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Approach 2 Quantitative Uncertainty Estimates for CH_4 and CO_2 Emissions from Petroleum Systems (MMT CO_2 Eq. and Percent)

Source	Gas	2016 Emission Estimate (MMT CO_2 Eq.)[b]	Uncertainty Range Relative to Emission Estimate[a] (MMT CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Petroleum Systems	CH_4	37.7	25.0	51.9	-34%	+38%
Petroleum Systems[c]	CO_2	23.3	15.5	32.2	-34%	+38%

[a] Range of emission estimates estimated by applying the 95 percent confidence intervals obtained from the Monte Carlo Simulation analysis conducted for the year 2017 CH_4 emissions.
[b] All reported values are rounded after calculation. As a result, lower and upper bounds may not be duplicable from other rounded values as shown in table.
[c] An uncertainty analysis for the petroleum systems CO_2 emissions was not performed. The relative uncertainty estimated (expressed as a percent) from the CH_4 uncertainty analysis was applied to the point estimate of petroleum systems CO_2 emissions.

GHGRP data, available starting in 2010 for refineries and in 2011 for other sources, have improved estimates of emissions from petroleum systems. Many of the previously available datasets were collected in the 1990s. To develop a consistent time series for sources with new data, EPA reviewed available information on factors that may have resulted in changes over the time series (e.g., regulations, voluntary actions) and requested stakeholder feedback on trends as well. For most sources, EPA developed annual data for 1993 through 2009 or 2014 by interpolating activity data or emission factors or both between 1992 and 2010 or 2015 data points. Information on time-series consistency for sources updated in this year's Inventory can be found in the Recalculations Discussion below, with additional detail provided in supporting memos (relevant memos are cited in the Recalculations Discussion). For information on other sources, please see the Methodology Discussion above and Annex 3.5.

QA/QC and Verification Discussion

The petroleum systems emission estimates in the Inventory are continually being reviewed and assessed to determine whether emission factors and activity factors accurately reflect current industry practices. A QA/QC analysis was performed for data gathering and input, documentation, and calculation. QA/QC checks are consistently conducted to minimize human error in the model calculations. EPA performs a thorough review of information associated with new studies, GHGRP data, regulations, public webcasts, and the Natural Gas STAR Program to assess whether the assumptions in the Inventory are consistent with current industry practices. EPA has a multi-step data verification process for GHGRP data, including automatic checks during data-entry, statistical

analyses on completed reports, and staff review of the reported data. Based on the results of the verification process, EPA follows up with facilities to resolve mistakes that may have occurred.[2]

As in previous years, EPA conducted early engagement and communication with stakeholders on updates prior to public review. EPA held a stakeholder workshop on greenhouse gas data for oil and gas in October of 2018, and webinars in June of 2018 and February of 2019. EPA released memos detailing updates under consideration and requesting stakeholder feedback. Stakeholder feedback received through these processes is discussed in the Recalculations Discussion and Planned Improvements sections below.

In recent years, several studies have measured emissions at the source level and at the national or regional level and calculated emission estimates that may differ from the Inventory. There are a variety of potential uses of data from new studies, including replacing a previous estimate or factor, verifying or QA of an existing estimate or factor, and identifying areas for updates. In general, there are two major types of studies related to oil and gas greenhouse gas data: studies that focus on measurement or quantification of emissions from specific activities, processes, and equipment, and studies that use tools such as inverse modeling to estimate the level of overall emissions needed to account for measured atmospheric concentrations of greenhouse gases at various scales. The first type of study can lead to direct improvements to or verification of Inventory estimates. In the past few years, EPA has reviewed and in many cases, incorporated data from these data sources. The second type of study can provide general indications on potential over- and under-estimates. A key challenge in using these types of studies to assess Inventory results is having a relevant basis for comparison (i.e., the independent study should assess data from the Inventory and not another data set, such as EDGAR). In an effort to improve the ability to compare the national-level Inventory with measurement results that may be at other scales, a team at Harvard University along with EPA and other coauthors developed a gridded inventory of U.S. anthropogenic methane emissions with 0.1 degree x 0.1 degree spatial resolution, monthly temporal resolution, and detailed scale-dependent error characterization.[3] The gridded methane inventory is designed to be consistent with the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014* estimates for the year 2012, which presents national totals.[4]

Recalculations Discussion

EPA received information and data related to the emission estimates through GHGRP reporting, the annual Inventory formal public notice periods, stakeholder feedback on updates under consideration, and new studies. In June, October, and November 2018, EPA released draft memoranda that discussed changes under consideration and requested stakeholder feedback on those changes. The EPA then created updated versions of the memoranda to document the methodology implemented into the current Inventory.[5] The EPA memorandum *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2017: Other Updates Under Consideration* (Nov. 2018 *Other Updates* memo) is cited in the Recalculations Discussion below.

EPA thoroughly evaluated relevant information available and made updates to exploration and production segment methodologies for the Inventory, specifically: using GHGRP data to calculate emissions and activity factors for oil well completions and workovers with hydraulic fracturing; using DrillingInfo data (DrillingInfo 2018) to calculate well drilling activity; and revising the basis for calculating the number of active wells represented in GHGRP reporting. In addition, certain sources did not undergo methodological updates, but CH_4 and/or CO_2 emissions changed by greater than 0.05 MMT CO_2 Eq., comparing the previous estimate for 2016 to the current (recalculated) estimate for 2016 (the emissions changes were mostly due to GHGRP data submission revisions); these sources are discussed below and include production tanks, associated gas venting and flaring, miscellaneous production flaring, pneumatic controllers, chemical injection pumps, heaters, and refineries.

Finally, emissions estimates were included for N_2O from flaring activities in the exploration, production, and refineries segments, and for CO_2 from the crude oil transportation segment.

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[2] See <https://www.epa.gov/sites/production/files/2015-07/documents/ghgrp_verification_factsheet.pdf>

[3] See <https://www.epa.gov/ghgemissions/gridded-2012-methane-emissions>

[4] See <https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990-2014>

[5] Stakeholder materials including draft and final EPA memoranda for the current (i.e., 1990 to 2017) Inventory are available at <https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems>.

The combined impact of revisions to 2016 petroleum systems CH_4 emissions, compared to the previous Inventory, is a decrease from 38.6 to 38.2 MMT CO_2 Eq. (0.4 MMT CO_2 Eq., or 1 percent). The recalculations resulted in an average increase in CH_4 emission estimates across the 1990 through 2016 time series, compared to the previous Inventory, of 3.3 MMT CO_2 Eq., or 10 percent, with the largest increases in the estimates for 2005 to 2013 due to the revised data on hydraulically fractured oil well completions.

The combined impact of revisions to 2016 petroleum systems CO_2 emissions, compared to the previous Inventory, is a decrease from 22.8 to 22.2 MMT CO_2 (0.6 MMT CO_2, or 2 percent). The recalculations resulted in an average increase in emission estimates across the 1990 through 2016 time series, compared to the previous Inventory, of 0.6 MMT CO_2 Eq., or 4 percent.

In [REF _Ref510007109 \h] and [REF _Ref536776217 \h] below are categories in Petroleum Systems with updated methodologies or with recalculations resulting in a change of greater than 0.05 MMT CO_2 Eq., comparing the previous estimate for 2016 to the current (recalculated) estimate for 2016. For more information, please see the Recalculations Discussion below.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Recalculations of CO_2 in Petroleum Systems (MMT CO_2)

	Previous Estimate Year 2016, 2018 Inventory	Current Estimate Year 2016, 2019 Inventory	Current Estimate Year 2017, 2019 Inventory
Exploration	+	**1.2**	**1.7**
HF Oil Well Completions	+	1.2	1.6
Production	***19.0***	**17.0**	**18.0**
Tanks	*7.4*	5.9	4.4
Associated Gas Venting & Flaring	*9.1*	8.6	10.5
Miscellaneous Flaring	*2.5*	2.2	2.6
HF Oil Well Workovers	+	0.2	0.3
Transportation	*NE*	+	+
Refining	**3.7**	**4.0**	**3.7**
Petroleum Systems Total	***22.8***	**22.2**	**23.3**

NE (Not Estimated)
+ Does not exceed 0.05 MMT CO_2.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Recalculations of CH_4 in Petroleum Systems (MMT CO_2 Eq.)

	Previous Estimate Year 2016, 2018 Inventory	Current Estimate Year 2016, 2019 Inventory	Current Estimate Year 2017, 2019 Inventory
Exploration	***2.1***	**0.5**	**0.4**
HF Oil Well Completions	2.0	0.4	0.3
Production	***35.4***	**36.8**	**36.4**
Pneumatic Controllers	*18.5*	20.5	20.9
Tanks	*3.2*	2.6	1.5
Heaters	*0.8*	0.7	0.7
Chemical Injection Pumps	*2.0*	2.1	2.0
HF Oil Well Workovers	+	0.1	0.1
Transportation	***0.2***	**0.2**	**0.2**
Refining	***0.9***	**0.7**	**0.7**
Petroleum Systems Total	***38.6***	**38.2**	**37.7**

+ Does not exceed 0.05 MMT CO_2.

Exploration

HF Oil Well Completions (Methodological Update)

EPA revised the HF oil well completions methodology by establishing four control categories (non-REC with venting, non-REC with flaring, REC with venting, and REC with flaring) and developing new activity and emission factors for these categories. The new methodology is detailed in the Nov. 2018 *Other Updates* memo. The previous factors (for controlled and uncontrolled event categories) relied on data analysis from the 2015 NSPS OOOOa rulemaking proposal. As described above in the Methodology discussion, EPA has newly calculated year-specific activity factors (fraction of events in each category) and emission factors for years 2016 forward using GHGRP data. To estimate emissions over the time series, EPA applied the year 2016 emission factors for all prior years and developed activity factors by following the existing methodology for HF gas well events combined with oil well-specific assumptions regarding when controls became prevalent. For HF oil well event activity factors, the following assumptions are applied: (1) for years 1990 to 2007, all completions and workovers are non-REC, and 10 percent of events flare; (2) for the first year in which GHGRP data are available, 2016, control fractions across the four categories are developed directly from reported GHGRP data; and (3) for intermediate years, 2008 to 2015, control fractions are developed through linear interpolation. This approach produces activity factors across the time series that are generally consistent with the previous assumption that oil well RECs are introduced beginning in year 2008, during which 7 percent of completions and workovers are REC, and 10 percent of both REC and non-REC events flare. EPA did not change the methodology of calculating total activity for this source, which relies on analyzing DrillingInfo data (DrillingInfo 2018) to obtain the total HF oil well completion event count in each year of the time series. Stakeholder feedback supported an approach of using GHGRP data to update activity and emissions factors on an annual basis from 2016 forward.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: HF Oil Well Completions National CH_4 Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
HF Completions: Non-REC with Venting	110,326	171,881	227,632	171,542	60,488	7,043	2,168
HF Completions: Non-REC with Flaring	360	560	2,502	2,788	1,804	1,018	1,791
HF Completions: REC with Venting	0	0	4,800	6,081	4,383	2,714	2,223
HF Completions: REC with Flaring	0	0	7,707	9,764	7,037	4,358	6,424
Total Emissions	**110,685**	**172,441**	**242,642**	**190,175**	**73,712**	**15,132**	**12,606**
Previous Estimate	*20,796*	*31,070*	*109,422*	*120,925*	*78,525*	*78,525*	*NA*

NA (Not Applicable)

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: HF Oil Well Completions National CO_2 Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
HF Completions: Non-REC with Venting	2.5	4.0	5.3	4.0	1.4	0.2	0.2
HF Completions: Non-REC with Flaring	79	123	547	610	395	223	410
HF Completions: REC with Venting	0.0	0.0	0.3	0.3	0.3	0.2	0.1
HF Completions: REC with Flaring	0.0	0.0	1,661	2,104	1,517	939	1,209
Total Emissions	**81.2**	**126.5**	**2,214**	**2,719**	**1,913**	**1,162**	**1,619**
Previous Estimate	*1.2*	*1.7*	*6.1*	*6.7*	*4.4*	*4.4*	*NA*

NA (Not Applicable)

Well Drilling (Methodological Update)

EPA updated the methodology for estimating the number of oil wells drilled across the time series to use DrillingInfo data (DrillingInfo 2018). The new methodology is detailed in the Nov. 2018 *Other Updates* memo. In previous Inventories, the U.S. Department of Energy's Energy Information Administration (DOE/EIA) *Monthly*

Energy Review well drilling activity data set was used to develop well drilling activity inputs, but this publication does not provide data after year 2010. EPA therefore developed a methodology of analyzing DrillingInfo data to estimate counts of oil wells drilled in each time series year, 1990 through 2017. These activity data for select years are shown in [REF _Ref536776124 \h] below.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Count of Oil Wells Drilled

Source	1990	2005	2013	2014	2015	2016	2017
Oil Wells Drilled	19,919	18,216	35,671	36,910	17,359	10,242	10,242
Previous Estimate	*17,234*	*12,053*	*17,774[a]*	*17,774[a]*	*17,774[a]*	*17,774[a]*	*NA*

a – Year-specific data not available; the year 2010 estimate was assigned as a surrogate value.
NA (Not Applicable)

Production

HF Oil Well Workovers (Methodological Update)

EPA revised the HF oil well workovers methodology to use the same general approach as described above for HF oil well completions. EPA revised the oil well workovers methodology by separating HF and non-HF events, then establishing four control categories for HF events (non-REC with venting, non-REC with flaring, REC with venting, and REC with flaring) and developing new activity and emission factors for these categories. The new methodology is detailed in the Nov. 2018 *Other Updates* memo. The previous methodology did not use separate emissions or activity assumptions for HF versus non-HF workover events. As described above in the Methodology discussion, EPA has newly calculated year-specific activity factors (fraction of events in each category) and emission factors for years 2016 forward using GHGRP data. To estimate emissions over the time series, EPA applied the year 2016 emission factors for all prior years and developed activity factors by following the existing methodology for HF gas well events combined with oil well-specific assumptions regarding when controls became prevalent. For HF oil well event activity factors, the following assumptions are applied: (1) for years 1990 to 2007, all completions and workovers are non-REC, and 10 percent of events flare; (2) for the first year in which GHGRP data are available, 2016, control fractions across the four categories are developed directly from reported GHGRP data; and (3) for intermediate years, 2008–2015, control fractions are developed through linear interpolation. This approach produces activity factors across the time series that are generally consistent with the previous assumption that oil well RECs are introduced beginning in year 2008, during which 7 percent of completions and workovers are REC, and 10 percent of both REC and non-REC events flare. EPA also updated the methodology of calculating total activity for this source; EPA applies the existing assumption used for HF gas wells, that 1% of HF wells are worked over in a given year. Stakeholder feedback supported an approach of using GHGRP data to update activity and emissions factors on an annual basis from 2016 forward.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: HF Oil Well Workovers National CH_4 Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
HF Workovers: Non-REC with Venting	31,119	35,018	22,290	17,601	10,808	3,318	0
HF Workovers: Non-REC with Flaring	101	114	142	148	142	130	114
HF Workovers: REC with Venting	0	0	745	966	1,146	1,275	678
HF Workovers: REC with Flaring	0	0	485	629	746	830	1,229
Total Emissions	**31,220**	**35,132**	**23,662**	**19,344**	**12,842**	**5,552**	**2,022**
Previous Estimate[a]	*77*	*65*	*79*	*82*	*82*	*78*	*NA*

NA (Not Applicable)
[a] Estimate includes emissions for HF and non-HF workovers.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: HF Oil Well Workovers National CO_2 Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
HF Workovers: Non-REC with Venting	0.7	0.8	0.5	0.4	0.2	0.1	0.0
HF Workovers: Non-REC with Flaring	22.2	25.0	31.1	32.3	31.1	28.4	26.2
HF Workovers: REC with Venting	0.0	0.0	0.0	0.1	0.1	0.1	0.0
HF Workovers: REC with Flaring	0.0	0.0	104.5	135.5	160.7	178.8	231.3
Total Emissions	**22.9**	**25.8**	**136.1**	**168.3**	**192.1**	**207.4**	**257.5**
Previous Estimate[a]	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*NA*

NA (Not Applicable)
[a] Estimate includes emissions for HF and non-HF workovers.

Tanks (Recalculation with Updated Data)

Production tank CH_4 and CO_2 emissions decreased in the current Inventory, compared to the previous Inventory. This change was due to GHGRP submission revisions and updated production data (see the Oil Production discussion below). For CO_2 emissions, in general, a smaller fraction of the GHGRP tank throughput went through tanks with flares and certain GHGRP-based emission factors were lower. For CH_4, while a larger fraction of the GHGRP tank throughput went through tanks without controls, the calculated GHGRP-based emission factors were lower.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Production Storage Tank National CH_4 Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
Large Tanks w/ Flares	0	2,510	5,649	6,704	7,230	5,105	5,687
Large Tanks w/ VRU	0	1,133	2,550	3,026	3,263	19,180	8,963
Large Tanks w/o Control	209,643	52,011	38,001	45,093	48,631	66,448	40,056
Small Tanks w/ Flares	0	15	34	41	44	22	44
Small Tanks w/o Flares	4,246	2,041	2,992	3,551	3,830	3,358	2,248
Malfunctioning Dump Valves	3,998	2,345	3,770	4,473	4,824	8,079	4,339
Total Emissions	**217,887**	**60,055**	**52,997**	**62,887**	**67,821**	**102,191**	**61,336**
Previous Estimate	*257,923*	*84,409*	*65,467*	*76,752*	*82,496*	*127,025*	*NA*

NA (Not Applicable)

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Production Storage Tank National CO_2 Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
Large Tanks w/ Flares	0	2,619	5,896	6,997	7,546	5,843	4,380
Large Tanks w/ VRU	0	5	11	13	14	4.6	4
Large Tanks w/o Control	23	6	4	4.9	5	7	5
Small Tanks w/ Flares	0	2	5	6	7	17	15
Small Tanks w/o Flares	6	3	4	5	5	5	3
Malfunctioning Dump Valves	17	10	16	19	20	18	15
Total Emissions	**46**	**2,645**	**5,937**	**7,045**	**7,598**	**5,894**	**4,422**
Previous Estimate	*53*	*3,444*	*6,922*	*8,115*	*8,722*	*7,351*	*NA*

NA (Not Applicable)

Pneumatic Controllers (Recalculation with Updated Data)

Pneumatic controller CH_4 emissions increased in the current Inventory, compared to the previous Inventory, due to GHGRP submission revisions and the use of GHGRP well counts from the facility overview table (see the Well Counts discussion below). The well count change shifted certain controllers from being assigned to natural gas systems to petroleum systems. Pneumatic controller CH_4 emissions increased by an average of 5 percent across the 1990 to 2016 time series.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Pneumatic Controller National CH_4 Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
Pneumatic Controllers: High Bleed	724,225	418,481	100,587	87,778	77,849	82,071	52,265
Pneumatic Controllers: Low Bleed	49,429	43,906	29,291	28,589	25,341	17,415	19,162
Pneumatic Controllers: Int Bleed	0	238,603	613,112	660,145	682,514	718,683	765,378
Total Emissions	**773,655**	**700,990**	**742,990**	**776,512**	**785,704**	**818,169**	**836,804**
Previous Estimate	*765,975*	*663,461*	*687,210*	*715,768*	*720,996*	*739,125*	*NA*

NA (Not Applicable)

Associated Gas Venting and Flaring (Recalculation with Updated Data)

Associated gas venting and flaring CO_2 emissions decreased for 2016 and increased for 1990 through 2015 in the current Inventory, compared to the previous Inventory. Compared to the previous inventory, on average, calculated CO_2 emissions increased across the 1990 to 2015 time series by 20 percent, and decreased by 6 percent for 2016. This change was due to GHGRP submission revisions and updated production data (see the Oil Production discussion below). The emission calculations are performed at a basin-level, and the changes impacted each basin uniquely. However, the changes in CO_2 emissions were mainly driven by the Permian Basin data.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Associated Gas Venting and Flaring National CO_2 Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
Associated Gas Venting	21	11	11	12	13	6	19
Associated Gas Flaring	5,172	3,925	10,384	12,711	13,955	8,587	10,506
Total Emissions	**5,193**	**3,937**	**10,395**	**12,723**	**13,968**	**8,593**	**10,525**
Previous Estimate	*4,028*	*3,314*	*9,193*	*11,248*	*12,234*	*9,108*	*NA*

NA (Not Applicable)

Miscellaneous Production Flaring (Recalculation with Updated Data)

Miscellaneous production flaring CO_2 emissions decreased in most years of the current Inventory, except for an increase in 2015, compared to the previous Inventory. While there was generally a consistent decrease in CO_2 emissions in the current Inventory, there were several underlying factors that impacted the changes each year; GHGRP submission revisions, use of GHGRP well counts from the facility overview table (see the Well Counts discussion below), a correction to the linear interpolation calculation for emission factors in years 1993 through 2014, and updated production data (see the Oil Production discussion below). In addition, the emission calculations are performed at a basin-level, and the changes impacted each basin uniquely.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Miscellaneous Production Flaring National CO_2 Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
Misc. Flaring	0	800	2,487	3,157	3,571	2,201	2,631
Previous Estimate	*0*	*929*	*2,541*	*3,181*	*3,418*	*2,455*	*NA*

NA (Not Applicable)

Chemical Injection Pumps (Recalculation with Updated Data)

Chemical injection pump CH_4 emissions increased by an average of 1.4 percent over the time series and certain recent years increased by approximately 3 percent for the current Inventory, compared to the previous Inventory. The emissions increases are due to updated well counts (see the Well Counts discussion below); emission factors and activity factors were not updated.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Chemical Injection Pump National CH_4 Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
Chemical Injection Pump	49,465	67,785	83,972	87,212	86,114	83,215	81,660
Previous Estimate	*49,131*	*66,585*	*82,084*	*84,934*	*85,016*	*80,974*	*NA*

NA (Not Applicable)

Heaters (Recalculation with Updated Data)

Combustion CH_4 emissions from heaters decreased by an average of approximately 22 percent each year of the time series in the current Inventory, compared to the previous Inventory. The decrease is due to a decrease in total oil production in each year, the applicable activity data for heaters, which was updated for the current Inventory (see the Oil Production discussion below).

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Heater National CH_4 Emissions (Metric Tons CH_4)

Source	1990	2005	2013	2014	2015	2016	2017
Heater	23,935	14,038	22,570	26,782	28,883	26,504	28,051
Previous Estimate	*26,944*	*18,991*	*27,350*	*32,065*	*34,465*	*32,446*	*NA*

NA (Not Applicable)

Well Counts (Recalculation with Updated Data)

For total national well counts, EPA has used a more recent version of the DrillingInfo data set (DrillingInfo 2018) to update well counts data in the Inventory. EPA also updated the DrillingInfo data processing methodology to more accurately count wells in states with lease-level reporting (e.g., Kansas), which resulted in slight increased counts across the time series. While this was not a significant recalculation (increases are 2 to 3 percent across the time series), this is a key input to the Inventory, so results are highlighted here.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Producing Oil Well Count Data

Oil Well Count	1990	2005	2013	2014	2015	2016	2017
Number of Oil Wells	564,090	480,482	582,769	605,259	597,635	577,515	566,726
Previous Estimate	*553,899*	*469,632*	*569,670*	*589,450*	*590,017*	*561,964*	*NA*

NA (Not Applicable)

In October 2018, EIA released an updated time series of national oil and gas well counts (covering 2000 through 2017). EIA estimates 991,000 total producing wells for year 2017. EPA's total well count for this year is 978,176. EPA's well counts in recent time series years are generally 2 percent lower than EIA's. EIA's well counts include side tracks, completions, and recompletions, and therefore are expected to be higher than EPA's which include only producing wells. EPA and EIA use a different threshold for distinguishing between oil versus gas (EIA uses 6 mcf/bbl, while EPA uses 100 mcf/bbl), which results in EIA having a lower fraction of oil wells and a higher fraction of gas wells than EPA.

For the count of wells included in GHGRP reporting (used to develop wellhead-based emissions and activity factors), EPA previously referenced the wellhead counts contained within the reporting table for onshore production equipment leak emissions. Due to updated reporting requirements for year 2017 forward, well counts provided as part of the facility overview information (i.e., wells producing at the end of the calendar year plus wells removed

from production in a given year) provide more complete estimates. Therefore, EPA used well counts from the facility overview table for source-specific methodologies that rely on GHGRP reported well counts in the current Inventory. Comparing the GHGRP well counts from the facility overview table to the equipment leaks table: a larger population of the wells were reported as "oil" production type in the facility overview information table, compared to the equipment leaks table, which generally led to increased activity and emissions for petroleum systems; for example, as discussed in the sections above, production segment emissions from pneumatic controllers and miscellaneous production flaring increased.

Oil Production

EPA reviewed the national oil production data that were previously used in the Inventory and determined a more appropriate dataset were available. In previous Inventories, production from the EIA's *Monthly Energy Review* were used; specifically, Table 3.1 Petroleum Overview, "Total Crude Oil Field Production". However, this dataset includes both onshore and offshore production and did not distinguish between the two. EIA provides more detailed production data in an online database, including specifically reporting federal offshore production.[6] The EIA online database production data were used for the current Inventory and federal offshore production data were excluded. This meant the production values decreased across the time series, but are more specific to onshore production. The emission sources that rely on oil production as an activity driver and that were impacted the most by this change are production tanks, associated gas venting and flaring, miscellaneous production flaring, and heaters (all of which are discussed above). In addition, oil production data are activity drivers for estimating fugitive emissions from production compressors and the sales area (loadings), and emissions due to pressure relief valve releases.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Oil Production Data (Million Barrels)

Source	1990	2005	2013	2014	2015	2016	2017
Oil Production	2,385	1,399	2,249	2,668	2,878	2,641	2,795
Previous Estimate	*2,685*	*1,892*	*2,725*	*3,195*	*3,434*	*3,233*	*NA*

NA (Not Applicable)

Floating Roof Tanks

EPA removed the line item estimate for production segment floating roof tanks that was included in previous Inventories. The number of floating roof tanks and their emissions were minimal in the context of the petroleum production segment, and available data are limited; data on the number of floating roof tanks are only available for 1995, and the 1995 count is applied to all other years. EPA sought stakeholder input on whether and how to include floating roof tank emission estimates in the production segment and did not receive objections to the removal of this source. The emission estimate for this source in the previous Inventory was 159 metric tons CH_4 in each year, or 0.01 percent of CH_4 emissions in year 2016.

Crude Oil Transportation

EPA newly calculated CO_2 emissions from crude oil transportation in the current Inventory. Prior Inventories did not calculate CO_2 emissions from crude oil transportation. CO_2 emission factors were calculated by multiplying the CH_4 emission factors for each source by a conversion factor, which is the ratio of CO_2 content and CH_4 content in whole crude post-separator. Total CO_2 emissions from crude oil transportation are included in table X below, and emissions for each source can be found in Annex 3.5.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Crude Oil Transportation National CO_2 Emissions (kt CO_2)

Source	1990	2005	2013	2014	2015	2016	2017
Crude Oil Transportation	0.9	0.7	1.0	1.2	1.2	1.1	1.1

[6] Available at <https://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm>

Recalculations due to updated activity data for the quantity of petroleum transported by barge or tanker in the crude oil transportation segment did not result in a change in CH_4 emissions for 1990 to 2015. Updated activity data for 2016 resulted in a decrease in calculated CH_4 emissions of approximately 3 percent.

Refining

There are minimal changes in recalculated CH_4 and CO_2 emissions for 1990 to 2015 for this segment (e.g., average change is less than 0.1 percent each year). However, recalculations for 2016 resulted in CO_2 emissions increasing by 8 percent and CH_4 emissions decreasing by 24 percent. The 2016 emissions changes are due to GHGRP submission revisions.

N_2O Emissions

EPA newly calculated N_2O emissions in the current Inventory, as discussed in the Nov. 2018 *Other Updates* memo. Prior Inventories did not calculate N_2O emissions from petroleum systems. For each flaring emission source calculation methodology which uses GHGRP data, the existing source-specific methodology was applied to calculate N_2O emission factors. This update was applied for flaring sources in the exploration, production, and refining segments.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: N_2O National Emissions (Metric Tons N_2O)

Source	1990	2005	2013	2014	2015	2016	2017
Exploration	**0.6**	**0.6**	**4.3**	**5.2**	**3.8**	**2.1**	**2.5**
HF Completions with Flaring	0.1	0.2	3.8	4.7	3.3	2.0	2.5
Non-Completion Well Testing with Flaring	0.4	0.4	0.4	0.5	0.5	0.1	0.1
Production	**14.8**	**17.9**	**43.6**	**53.1**	**58.5**	**42.8**	**42.4**
Associated Gas Flaring	14.8	11.0	26.3	32.1	35.5	25.9	28.2
Storage Tanks with Flaring	NO	5.7	12.7	15.1	16.3	12.6	9.0
Misc. Production Flaring	NO	1.2	4.3	5.6	6.3	4.0	4.9
HF Workovers with Flaring	+	+	0.2	0.3	0.3	0.4	0.4
Crude Oil Transportation	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
Refining	**30.7**	**34.8**	**34.2**	**32.4**	**39.1**	**38.8**	**36.4**
Refinery Flares	30.7	34.8	34.2	32.4	39.1	38.8	36.4
Total	**46.1**	**53.3**	**82.0**	**90.7**	**101.4**	**83.7**	**81.3**

NE (Not Estimated)
NO (Not Occuring)
+ less than 0.05

Planned Improvements

Offshore Platforms

EPA is considering updates to the offshore platform emissions calculation methodology, as discussed in the memorandum *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016: Additional Revisions Under Consideration*.[7] The current emission factors were based on data from the 2011 DOI/Bureau of Ocean Energy Management's (BOEM) dataset, and 2014 BOEM data are available. A different source for platform counts is also being considered.

[7] See <https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems>

Well-Related Activity Data

EPA will continue to assess available data, including data from the GHGRP and stakeholder feedback on considerations, to improve activity estimates for sources that rely on well-related activity data. For example, EPA will review GHGRP data regarding reported well workover rates and seek information on other data sets that might inform estimates of non-hydraulically fractured oil well completions and workovers.

Upcoming Data, and Additional Data that Could Inform the Inventory

EPA will assess new data received by the Methane Challenge Program on an ongoing basis, which may be used to confirm or improve existing estimates and assumptions.

EPA continues to track studies that contain data that may be used to update the Inventory, such as an upcoming field study by American Petroleum Institute (API) on pneumatic controllers and separate studies by research groups that will examine offshore platform emissions. EPA will also continue to assess studies that include and compare both top-down and bottom-up estimates, and which could lead to improved understanding of unassigned high emitters (e.g., identification of emission sources and information on frequency of high emitters) as recommended in stakeholder comments.

EPA also continues to seek new data that could be used to assess or update the estimates in the Inventory. For example, stakeholder comments have highlighted areas where additional data that could inform the Inventory are currently limited or unavailable:

- Tank malfunction and control efficiency data.
- Activity data and emissions data for production facilities that do not report to GHGRP.
- Associated gas venting and flaring data on practices from 1990 through 2010.
- Refineries emissions data. One stakeholder noted a recent study (Lavoie et al. 2017) that measured three refineries and found higher average emissions than in the Inventory, and the stakeholder suggested that EPA evaluate the study and any additional information available on this source.
- Anomalous leak events.

EPA will continue to seek available data on these and other sources as part of the process to update the Inventory.

Box [STYLEREF 1 \s]-[SEQ Box * ARABIC \s 1]: Carbon Dioxide Transport, Injection, and Geological Storage – TO BE UPDATED FOR FINAL INVENTORY REPORT

Carbon dioxide is produced, captured, transported, and used for Enhanced Oil Recovery (EOR) as well as commercial and non-EOR industrial applications. This CO_2 is produced from both naturally-occurring CO_2 reservoirs and from industrial sources such as natural gas processing plants and ammonia plants. In the Inventory, emissions from naturally-produced CO_2 are estimated based on the specific application.

In the Inventory, CO_2 that is used in non-EOR industrial and commercial applications (e.g., food processing, chemical production) is assumed to be emitted to the atmosphere during its industrial use. These emissions are discussed in the Carbon Dioxide Consumption section. The naturally-occurring CO_2 used in EOR operations is assumed to be fully sequestered. Additionally, all anthropogenic CO_2 emitted from natural gas processing and ammonia plants is assumed to be emitted to the atmosphere, regardless of whether the CO_2 is captured or not. These emissions are currently included in the Natural Gas Systems and the Ammonia Production sections of the Inventory report, respectively.

IPCC includes methodological guidance to estimate emissions from the capture, transport, injection, and geological storage of CO_2. The methodology is based on the principle that the carbon capture and storage system should be handled in a complete and consistent manner across the entire Energy sector. The approach accounts for CO_2 captured at natural and industrial sites as well as emissions from capture, transport, and use. For storage specifically, a Tier 3 methodology is outlined for estimating and reporting emissions based on site-specific evaluations. However, IPCC (IPCC 2006) notes that if a national regulatory process exists, emissions information available through that process may support development of CO_2 emission estimates for geologic storage.

In the United States, facilities that produce CO_2 for various end-use applications (including capture facilities such as acid gas removal plants and ammonia plants), importers of CO_2, exporters of CO_2, facilities that conduct geologic sequestration of CO_2, and facilities that inject CO_2 underground, are required to report greenhouse gas data annually to EPA through its GHGRP. Facilities conducting geologic sequestration of CO_2 are required to develop and implement an EPA-approved site-specific monitoring, reporting and verification plan, and to report the amount of CO_2 sequestered using a mass balance approach.

GHGRP data relevant for this inventory estimate consists of national-level annual quantities of CO_2 captured and extracted for EOR applications for 2010 to 2016. However, for 2015 and 2016, data from EPA's GHGRP (Subpart PP) were unavailable for use in the current Inventory report due to data confidentiality reasons. The estimate for 2014 was held constant here to estimate 2015 and 2016 emissions. EPA will continue to evaluate the availability of additional GHGRP data and other opportunities for improving the emission estimates. For reporting year 2016, one facility reported data to the GHGRP under subpart RR (Geologic Sequestration of Carbon Dioxide). This facility reported 3.1 MMT of CO_2 sequestered in subsurface geological formations and 56 metric tons of CO_2 emitted from surface equipment leaks and vents.

These estimates indicate that the amount of CO_2 captured and extracted from natural and industrial sites for EOR applications in 2016 is 59.3 MMT CO_2 Eq. (59,318 kt) (see [REF _Ref317250364 \h * MERGEFORMAT] and [REF _Ref317250365 \h * MERGEFORMAT]). Site-specific monitoring and reporting data for CO_2 injection sites (i.e., EOR operations) were not readily available, therefore, the quantity of CO_2 captured and extracted is noted here for information purposes only; CO_2 captured and extracted from industrial and commercial processes is assumed to be emitted and included in emissions totals from those processes.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Quantity of CO_2 Captured and Extracted for EOR Operations (MMT CO_2)

Stage	1990	2005	2012	2013	2014	2015	2016
Capture Facilities	4.8	6.5	9.3	12.2	13.1	13.1	13.1
Extraction Facilities	20.8	28.3	48.9	47.0	46.2	46.2	46.2
Total	**25.6**	**34.7**	**58.1**	**59.2**	**59.3**	**59.3**	**59.3**

Note: Totals may not sum due to independent rounding.

Table [STYLEREF 1 \s]-[SEQ Table * ARABIC \s 1]: Quantity of CO_2 Captured and Extracted for EOR Operations (kt)

Stage	1990	2005	2012	2013	2014	2015	2016
Capture Facilities	4,832	6,475	9,267	12,205	13,093	13,093	13,093
Extraction Facilities	20,811	28,267	48,869	46,984	46,225	46,225	46,225
Total	**25,643**	**34,742**	**58,136**	**59,189**	**59,318**	**59,318**	**59,318**

Note: Totals may not sum due to independent rounding.

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